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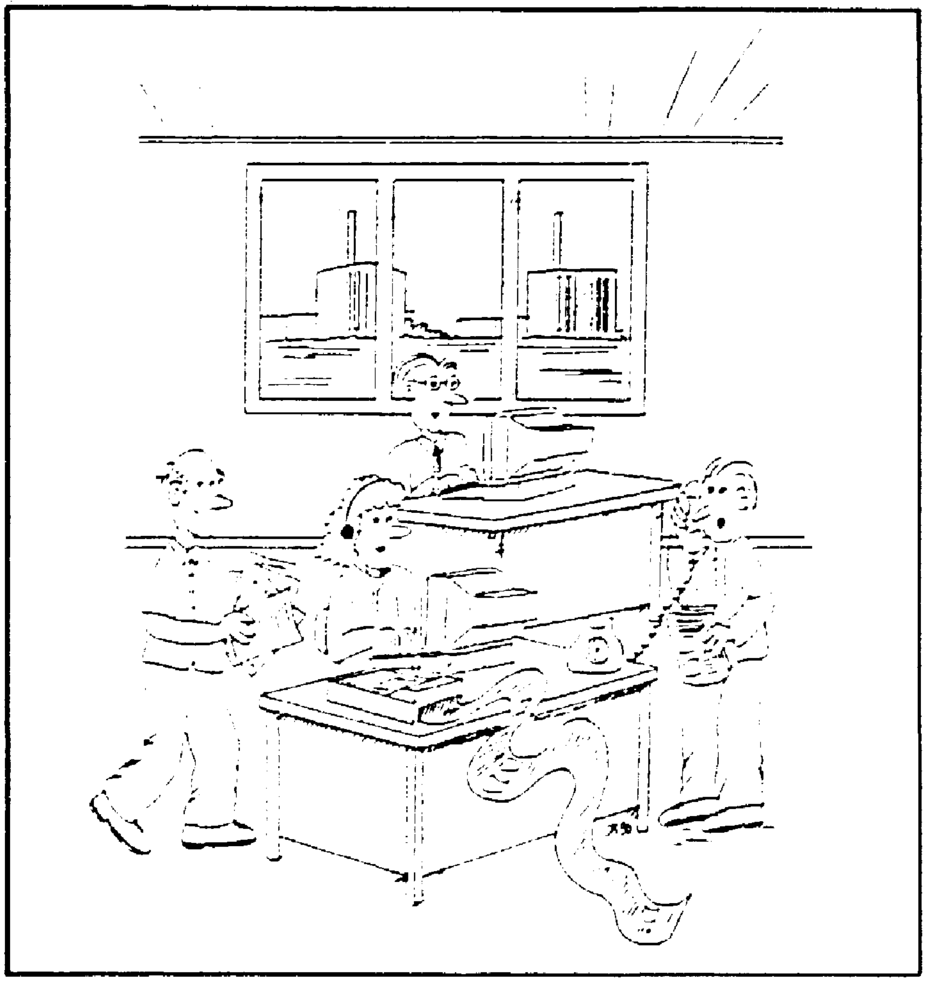
INFORMATION TECHNOLOGY FOR EMERGENCY MANAGEMENT



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Pohjoismainen atomienergia-yhdyselin

Nordic liaison committee for atomic energy

INFORMATION TECHNOLOGY FOR EMERGENCY MANAGEMENT

Final Report of the NKA Project INF 600

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ABSTRACT

Improved performance in emergency management by the use of modern information technology has been investigated. Limited parts of a preparedness system have been chosen based on analysis of drills with respect to emergency situations and real accidents. Specific functions relevant for the situation have been selected and implemented in prototype test systems. Finally, the usefulness of the prototype systems has been evaluated by experiments following specific scenarios.

Descriptors - INIS:
Decision Making; Education; Emergency Plans; Evaluation; Information Systems; Man-Machine Systems; Management; Organisational Models; Personnel; Testing.

SUMMARY

Increasing complexity of industrial processes in combination with recognition of errors that have occurred in handling emergency situations call for improved support for those who have to make decisions when accidents are developing.

The functionality and efficiency of emergency management is likely to be improved if advanced information technology is available. This has been investigated in a limited part of an emergency preparedness system. The investigation was done in a nuclear industry context, but attention has been paid to the similarities between different types of emergency situations, especially concerning the situation off-site, i.e. in the environment of a plant.

To be useful in an emergency situation, the tools given to the persons involved in an emergency preparedness organisation must not only be effective for the emergency management, they must also be self-explanatory and simple to use. Experience with such tools should be obtained from realistic drills, as it is of utmost importance that the users are familiar with the tools before they need them in an actual situation. It is unlikely that a person will experience a real emergency situation more than once in his/her entire lifetime, if any at all.

In this project, detailed analysis of accident and emergency scenarios was based on records from drills in nuclear installations. This analysis has revealed the complexity that must be faced in making emergency management organisations work properly. Efficient decision making and exchange of information in situations with high stress and work load are important for the proper functioning of emergency organisations. Consequently, to demonstrate the possible benefits of modern information technology for emergency management, functions that can improve the reliability of information exchange would be helpful.

For this purpose a few but important functions have been studied and tested under realistic circumstances. The functions include

- information handling,
- information transfer,

- reminder functions.

Using these functions, those responsible for the emergency management will be able to categorise and file messages in a way which makes the messages easy to access at a later time. Messages can also be formulated and received in a standardised manner to ensure that nothing is forgotten. Furthermore, reminder functions are partly built upon the emergency preparedness guide/plan, and partly developed to be used according to individual wishes of the user. Thus, selected messages can be presented within fixed time intervals or at a later preselected time.

The information related functions have been tested in two different emergency systems. The first is an on-site emergency management system, based on the actual preparedness organisation at the Finnish Nuclear Power Plant Loviisa. The second is the off-site emergency management system, based on the emergency preparedness organisation in Sweden.

First a detailed analysis of information flow in these two systems in case of an emergency was performed. Three individual centres, the County Emergency Organisation Centre (CEOC), the Reactor Safety Authority (SKI), and the Radiation Protection Authority (SSI), which are geographically separated, are the main actors in the off-site system, against only one, the Plant Emergency Organisation Centre, in the on-site system. The analysis has identified the type of information transferred in the main centres. From this analysis, data and knowledge required for an effective decision support system could be specified.

From an analysis of the organisational units involved, two specific centres were selected, the Plant Emergency Organisation Centre and the County Emergency Organisation Centre for the on-site and off-site organisations, respectively. They were used as test cases for development of an advanced message handling and reminder system. The system was analysed in detail with respect to the functions to be included, the need for data and knowledge bases, as well as the specific features desired. Finally, the system was implemented in two prototype systems, one for on-site and one for off-site.

The usefulness of these two prototype systems was then evaluated using two different methods: a conceptual evaluation in which the presence of needed functions is verified, and an empirical evaluation which is in fact a test of the functions implemented in the prototype systems.

The empirical evaluation involved experiments that were based on four different scenarios, two on-site and two off-site. The results obtained when using the new emergency support systems were compared with control conditions using "normal" information procedures in order to evaluate the benefits of the systems. As the prototype systems are covering only a part of the emergency management, it is important for the evaluation to arrange the scenarios to make sure that the implemented functions are in fact tried out.

The success of the information systems was measured by the quality of the status reports produced by the persons carrying out the experiments and on the extent to which they actually carried out the items in the emergency preparedness guide/plan. Furthermore, the evaluation considered the satisfaction of the persons using the systems. This was unveiled by interviews of those persons having performed both in a condition with the system and in the more traditional condition.

Prior to the experiments the test persons were given half an hour of introduction to the system and its various facilities. Despite the short time of introduction the test persons seemed to be familiar with the possible features of the system during the experiments. However, to avoid delay due to trivial problems they were provided with an experienced terminal operator to execute their orders so that practical man machine interface problems would not blur the experiments.

The test persons used for the evaluation of the systems were experts, able to perform optimally in most situations using the traditional preparedness system (in total five persons from the county authorities in Uppsala were involved in the off-site test and four persons from Loviisa Nuclear Power Plant in the on-site test). Owing to the skill of the test persons an extraordinary challenging emergency situation would have been needed to provoke errors using the traditional preparedness system and make visible the advantage of using the new and advanced system. However, when using the fairly simple test scenarios, the outcome of the experiments with the new system and the conventional one was similar, in both cases ending with the emergency under control. So, in defiance of the generally high user satisfaction - especially in the off-site evaluation - the evaluation of the emergency management did not give any statistically significant indication about the advantage of using the computerised system.

As mentioned, user satisfaction was generally high in the off-site evaluation. All the test persons found the system useful in the experiment and considered it to be useful also in a real emergency situation. Test persons in the on-site evaluation were somewhat less enthusiastic. It seems as if user satisfaction of the system - which was developed for a single person - is related to the test persons' normal way of acting: off-site persons normally work alone with contact to persons at distant destinations, on-site persons normally work in teams with direct face-to-face contact.

Test persons of both categories found the system well suited for training purpose in the emergency organisation, and the off-site persons - experts from the county authorities in Uppsala - expressed their interest in having some form of the system available, especially for this purpose.

It appears that support systems can be designed, using advanced information technology, that can facilitate decision making in emergency situations in complicated process plants. This concept is further pursued in a European Community follow-up project continuing the Nordic work described in this report.

SAMMANFATTNING

Syftet med projektet har varit att forbattra stodet for beslutsfattande i haveriorganisationer genom att utveckla och pröva användningen av modern informationsteknologi i en begränsad del av organisationen. Tillämpningen har varit inriktad på kärnkraftsindustrin, men likheter med andra typer av haverier har också beaktats, särskilt vad gäller haveriorganisationen utanför anläggningen.

För att kunna handskas med en haveri situation är det viktigt att de personer som finns i haveriorganisationen har de bästa verktyg som står att få. Dessa verktyg skall vara effektiva för arbetet i haveriorganisationen och samtidigt vara enkla att anvanda. Erfarenheten av sådana verktyg bor komma från realistiska övningar, eftersom det ar av yttersta vikt att personalen kan använda verktygen innan de skall utnyttjas i ett verkligt läge. Vidare ar det osannolikt att samma person kommer att uppleva mer än en haverisituation under sin livstid, om ens någon.

Utgångspunkten var en analys av olycks- och haveriscenarier, baserad på ovningar i kärnkraftssammanhang. Resultatet visade att den uppgift haveriorganisationer måste klara for att fylla sin funktion är komplex. Effektivt beslutsfattande och informationsutbyte i situationer med hog stress och arbetsbelastning forefaller vara särskilt viktiga för framgång. Darfor borde man inrikta sig på just dessa uppgifter när man vill demonstrera möjliga fordelar med att anvanda modern informationsteknologi for att förbattra arbetet i en haveriorganisation och undersoka dess effekter i realistiska sammanhang.

På grundval av denna analys valdes tre viktiga funktioner att ingå i ett protypsystem, namligen

- informationshantering

- informationsoverforing

- påminnelsefunktioner

Med hjalp av dessa funktioner, kan de som arbetar i haveriorganisationen kategorisera och lagra meddelanden på ett satt som gor det lätt att hämta fram dem vid behov. Meddelanden kan sändas och tas emot på ett standardiserat sätt som garanterar att inget utelämnas. Påminnelsefunktionerna bygger på åtgärdskalendern för haveriorganisationen, men tillåter också användaren att lägga in påminnelser om det han själv väljer att bli påmind om, antingen vid ett givet tillfälle eller vid olika tidpunkter.

Den fortsatta analysen inriktades på två system med olika ansvarsområden, men som ändå uppvisade betydande likheter: haveriorganisationen på ett kärnkraftverk, modellerad på det finska kärnkraftverket i Lovisa och haveriorganisationen på länstyrelsenivå, baserad på organisationen i Uppsala län i Sverige.

I projektets huvudfas genomfördes en detaljerad scenarioanalys i kombination med en begreppsanalys av fördelat beslutsfattande. Betydande arbetsinsatser har gjorts för att analysera informationsflödet i detalj vad gäller länsstyrelsens katastrofcentral, SSI, SKI, och kärnkraftverkets haveriorganisation och för att försöka identifiera vilken information som överförs mellan de viktigaste centra. På grundval av denna analys specificerades de data och den kunskap som krävs för att utveckla ett effektivt beslutstödssystem.

Från analysen av de inblandade organisatoriska enheterna har olika testfall valts ut för att utveckla och prova ett avancerat meddelandehanterings- och påminnelsesystem. Systemet har analyserats och specificerats i detalj vad gäller vilka funktioner som skall ingå, data- och kunskapsbaser och speciella egenskaper. Slutligen har det implementerats i form av två prototypsystem, ett för haveriorganisationen på kärnkraftverket och ett för länsstyrelsens haveriorganisation. Dessa beskrivs i olika avsnitt i rapporten.

I slutfasen har prototypsystemen utvärderats med två olika metoder: en begreppslig utvärdering enligt de principer som föreslagits av Rouse och en empirisk utvärdering som utgör en prövning av de funktioner som implementerats i protypsystemen.

I den empiriska utvärderingen av prototypsystemen genomfördes experiment baserade på fyra olika scenarier, två för organisationen på verket och två för länsstyrelseorganisationen. Prestationen i dessa scenarier med protypsystemet jämfördes med prestationen utan dessa system. De fyra scenarierna konstruerades med hänsyntagen till att prototypsystemen enbart omfattar en begränsad del av havariorganisationen.

Före själva experimentet fick försökspersonerna en introduktion till de olika möjligheter systemen erbjöd och en demonstration av hur dessa kunde användas. Denna introduktion tog ungefär en halvtimme. Trots den korta tiden föreföll personerna insatta i systemens möjligheter under själva experimenten. För att undvika fördröjningar beroende på triviala problem med själva handhavandet av systemen hade de dock hjälp av en erfaren operatör som skötte systemen under experimenten i enlighet med de anvisningar som gavs från försökspersonerna.

Experimenten ger information för en empirisk utvärdering av den kombinerade effekten av implementationsstrategin, den begreppsliga modellen som ligger bakom de system som utvecklats och de data- och kunskapsbaser som använts.

Utvärderingen har baserats på kvaliteten i de lägesrapporter som producerats av försökspersonerna i experimenten och på i vilken utsträckning de faktiskt utfört de olika moment som finns i de relevanta åtgärdskalendrarna. Vidare har utvärderingen grundats på data som belyser användarnas inställning till systemet, inhamtade från intervjuer efter det att försökspersonerna gått igenom ett scenario med och ett scenario utan systemet.

Utvärderingen av försökspersonernas prestation (fyra personer från Lovisaverket i utvärderingen av systemet i verkets organisation och fem personer från länsstyrelsen i Uppsala i utvärderingen av systemet i länsstyrelseorganisationen) avslöjade inga skillnader mellan betingelsen med systemet och betingelsen utan systemet. Detta berodde på den höga prestationen i kontrollbetingelsen, och både i denna betingelse och i betingelsen med systemet kunde försökspersonerna få haverisituationen under kontroll på ungefär samma tid. Detta resultat är inte förvånande i ljuset av erfarenheterna från andra försök att utvardera informations- och beslutsstödssystem, och diskuteras i rapporten.

Användartillfredsställelsen var i allmänhet hög i den utvärdering som gällde länsstyrelseorganisationen. Samtliga försökspersoner fann systemet användbart i experimentet, och ansåg att det också skulle kunna vara till nytta i en verklig haveriorganisation. Försökspersonerna i den utvardering som gallde systemet för karnkraftverket var dock mindre entusiastiska. Skillnaderna i tillfredsstallelse torde ha att gora med olikheter i det normala arbetssättet i de två organisationerna. I organisationen på verket kommunicerar områdesledaren huvudsakligen direkt med andra personer i staben, medan kommunikationen vad galler lansstyrelseorganisationen i större utstrackning galler personer och organisationer utanfor den egna staben.

Försökspersonerna i båda utvarderingarna var emellertid ense om att systemet var val agnat for att trana befattningshavare i haveriorganisationen, och forsokspersonerna från lansstyrelsen i Uppsala uttryckte intresse av att få tillgång till någon form av systemet for just detta andamål.

Projektet har visat att modern informationsteknologi kan bidra till stod for beslutsfattande i havariorganisationer i komplicerade processanlaggningar. Problemstallningen i det nordiska arbetet behandlas nu vidare i ett europeiskt projekt som skall avslutas med en demonstration i full skala.

CONTENTS

1. INTRODUCTION

Accidental situations are not unknown to people working in the present industrialised world. In most situations a failure which is not unfamiliar to the plant operators will show up, a limited number of people will be involved, hopefully - and normally - nobody will be harmed. After a couple of suitable procedures have been carried out, the situation will be under control. Some comments about the event including a moderate analysis have to be entered into the logbook, and the daily routine will continue as normal.

However, experience has shown that in recent years the rate of major industrial accidents, some of which have evolved into serious emergency situations, has increased drastically. In fact, the twentieth century has brought about a rapid rise in the rate of major industrial accidents and deaths of which half of the most serious have occurred since 1977 (Shrivastava 1987). As we approach the end of the century, we will see the proliferation of new and complex technologies in the industrialised world. At the same time, an increasing amount of hazardous technologies will be introduced in the developing countries, where industrial accidents are more common because the developing countries often lack an adequate industrial infrastructure. As a consequence, industrial accidents and emergencies are likely to become more frequent and larger in scope. However, even in the industrialised world the risk of severe accidents will increase as industries develop towards larger centralised production units. The consequence of this is an increased risk of heavy impact on the environments of the plants. This has led to the creation of large organisations prepared for accident and emergency management.

Experience gained from previous incidents and emergency drills has revealed the complexity that must be faced in making such organisations work properly. A well-functioning preparedness system puts heavy demands on communication, the accessibility of knowledge, availability of competence, and decision making. Furthermore, there must be enough flexibility for shifting between fixed rules and for developing new ways of coping with unforeseen situations. This is due to a number of problems which may arise in large and perhaps geographically separated organisations involved in emergency management. People with different backgrounds and responsibilities must co-operate smoothly in situations when the time factor is decisive for making the correct decisions. For example, in the Three Mile Island accident in 1979 more than 30 persons were gathered in the control room of the nuclear power plant trying to figure out what had happened and what should be done.

Problems observed within emergency preparedness organisations during drills or by analysis of accidental situations - e.g. in nuclear power plants - are omissions, confusion, and misunderstandings. Especially in the minutes just after the occurrence of an accident, operators may make the accident worse by taking precipitate action under the stress of the emergency. This happened at Three Mile Island (Milne 1987). Therefore, rapid communication of relevant information has been seen as an issue of special importance to be improved.

In addition, experience has shown that emergency situations that were previously expected to be of a local nature are now crossing national borders having influence several hundreds of kilometres from the source (Chernobyl and chemical accidents along the Rhine are examples of this). On this background it seems rational to introduce joint international efforts in order to develop systems capable of assisting the persons who are responsible in emergency management. In accordance with this the joint Nordic programme ("NKA/INF: Information Technology for Accident and Emergency Management") was started in 1985 with the purpose of evaluating how modern information technology can contribute to proper functioning of a preparedness system that will respond to disasters in complex technical plants. The aim has been to elaborate a prototype system for a limited part of a preparedness system and to test and, possibly, improve the functionality and efficiency of accident and emergency management. This was to be done by verifying, demonstrating, and validating the possible use of advanced information technology in the organisations responsible for emergency management. Experience gained from this exercise should reveal which parts of modern information technology could be useful in coping with emergency situations and which parts would be less beneficial from the points of view of efficiency in emergency situations, flexibility and quality in training, and last but not least, assurance of easy and up-to-date maintenance of a computer-assisted emergency management system.

There are many different roles that a computer system for emergency management could attend to. These could range from a simple system presenting raw data and making data communication possible to a very sophisticated system using a vast amount of features to elaborate on these data for presentation on a much higher level of abstraction and formulating possible argued solutions to problems. Systems could even be developed to perform specific procedures automatically.

In the INF project we want the human being to make the decisions based on detailed and structured information given by the system. It is definitely not intended to leave decision making to an automated decision system. This will require sufficient skill to foresee every kind of situation that might come up, contradicting one of the demands we have put on the system that the staff should be able to act in unforeseen and unfamiliar situations.

The original goal of the project was to investigate the benefit of using modern information technology in emergency management based on needs in the nuclear industry, but developed in a way which makes the results directly usable in other hazardous industries, for instance in the chemical industry and in the off-shore sector.

Following the Chernobyl accident in 1986 it was decided to focus more directly on the nuclear industry. Emergency situations in the nuclear industry have obvious similarities with those that arise in other types of industries.

The following list attempts to summarise some of the very general similarities:

- the systems are complex,
- several different organisations are involved,
- efficient communication is needed for managing the emergencies,
- the emergencies evolve in real time.

Strong similarities exist especially between the off-site situation of nuclear and chemical industries. In both a fairly large amount of energy and chemicals is stored in the plants, and during the emergency their effect may be spread and have consequences outside the plant itself. This means that the results of the INF project will be usable also in the chemical industry, especially as off-site emergency is concerned.

In emergency situations the staff in charge is acting in an unfamiliar and stressful situation. Nevertheless, it will have to face decisions that

- must be taken relatively fast,
- involve complex judgements,
- involve making trade-offs between partly incompatible demands,
- must be based on technical data to which it is difficult to get access,
- involve many decision makers and experts.

In order to evaluate the potential use of modern information technology to assist in such situations, prototype systems covering limited parts of an accident and emergency situation have been developed. These systems were to make use of computerised systems incorporating communication systems, data base and knowledge base technology, and applications of methods used in artificial intelligence.

In the project the on-site and off-site situations, respectively, have been treated separately with the on-site system based on the preparedness organisation at the Finnish Nuclear Power Plant, Loviisa, and the off-site situation based on the Swedish preparedness organisation. Yet, with the exception of specific adjustments, a vast amount of features are common for the two situations, giving mutual benefit in developing the systems. The national affiliations mentioned may result in the use of specific terms in the developed systems, related to these organisations.

The end product of the project has been recommendations for the introduction of advanced information technology in emergency organisations based on evaluation and validation of the prototype systems.

Already prior to the formal termination of the Nordic programme it was agreed to continue along the lines laid down in the programme to develop a complete decision support system for distributed decision making in emergency management. This programme was approved by the Commission of the European Communities (CEC), and has been officially started within the framework of ESPRIT 2 as "Project Number 2322: IT Support for Emergency Management - ISEM" with a commencement date of 1 January 1989. Especially in the starting phase this project has benefited substantially from the Nordic project.

2. PROBLEMS AND PRINCIPLES

Emergency management involves countless decisions, and these decisions require information. Thus, emergency management is, among many other things, an information management problem. As part of the NKA project, the information flows and decision making in on-site and off-site emergency management were analysed in drills concerned with nuclear power accidents. This led to the identification of a number of problems, which the information system should help alleviate, if not solve.

2.1 Basic functions and responsibilities in emergency management

There are two primary tasks in a nuclear power emergency: the accident management task and the emergency management task.

The primary goal of the first task is to control the behaviour of the plant, i.e., in practice to shut down the plant in a safe way. NUREG/CR - 4177 defines accident management in the following way:

Accident management is that set of actions taken by the plant operating crew to gain control of the outcome of an abnormal event at the earliest possible time and with the minimum adverse consequences. It is characterised by three component parts distinguishable in time: preparedness phase, response phase and recovery phase.

There is no corresponding official definition of the goal of the second task, emergency management, but analysis of the relevant documents governing the work of the county authorities suggests that this task has two principal components: to decide on protective measures, such as road blocks and evacuation, and to inform the public and other organisations so that the appropriate protective action can be taken.

Figure 2.1 shows the principal organisations involved in the emergency management task. It is important to note that the various EOCs have very similar functions. Thus, each EOC has a status department or some other unit for handling the continuous updating of the information about the situation. They have an expert or analysis department charged with the evaluation of the situation, and an information department for the task of informing the mass media and the public. An operational department, or some equivalent is also found for those organisations that need such a department.

The figure also shows the basic types of communication exchanged between various agencies, with an emphasis on the CEOC.

2.2 Problems observed in an emergency organisation

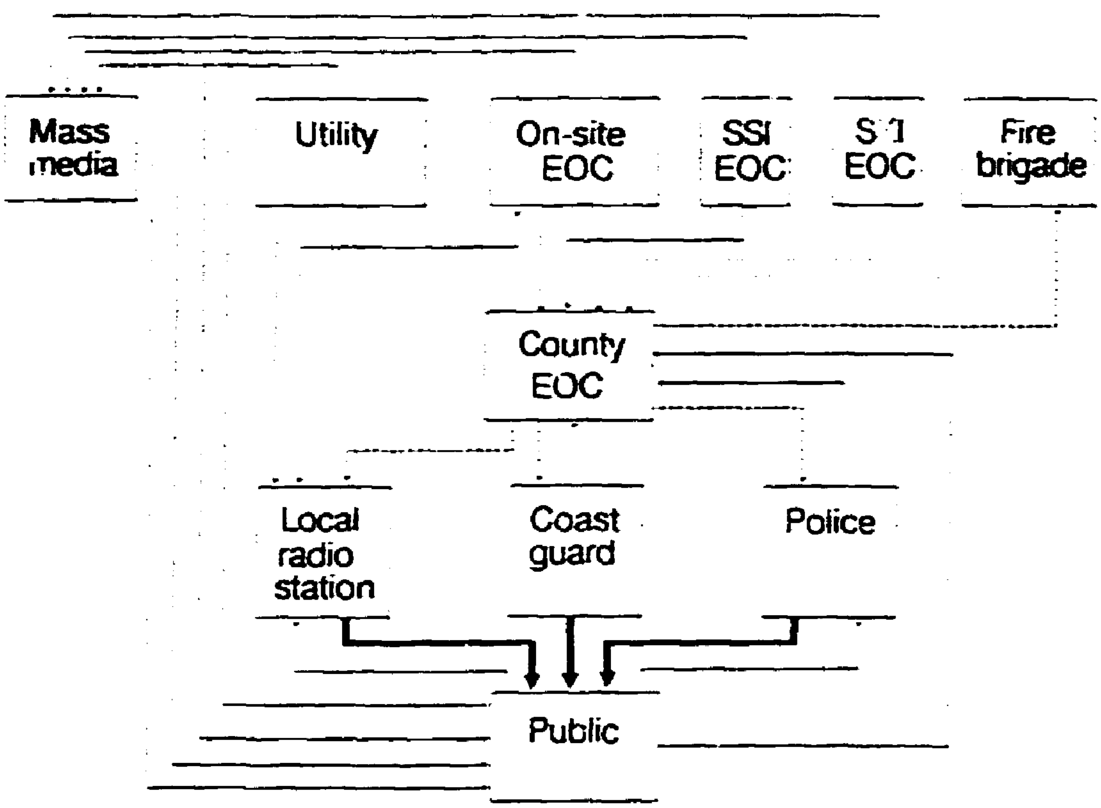
Analysis of results from drills suggest that omissions, confusion and misunderstanding are a common source of problems in the emergency organisation (Andersson & Holmström, 1987). The problems can be divided into four different categories.

The first has to do with the technical nature of the communication system (overload of channels, problems in operation). This may lead to delays in information transfer.

The second category of problems has to do with problems in ascertaining the correct order of events. If messages are not time tagged in appropriate ways, mistakes in the assessment of the order of events may result, and different decision makers may discuss the same situation, using data from different points in time.

The third category of problems stems from the conflict between the need to make strategic decisions and the need to manage the communication with other centres. If the communication is difficult, it may sometimes receive a low priority in relation to the more pressing strategic decision tasks, and pressing strategic tasks may lead to a low priority for transmitting information to other centres. As a consequence, there may be delays in the transfer of information to other parts of the emergency organisation.

The fourth category of problems is related to the content of the information communicated. Much of this information is highly technical, and not all of the personnel involved have the necessary competence for understanding this kind of information. This often leads to misunderstanding.



Relations

—— gives information

gives information, advice, consultative function

—— gives orders

······ gives operational direction

Figure 2.1. The organisations involved in off-site emergency management and the principal relations among them. This organisation reflects the set-up in Sweden.

Johansson, Andersson and Holmström (1986) observed a number of examples of such misunderstanding in their analysis of drills. For example, a list of isotopes was interpreted as a list of geographical co-ordinates, and a report about the loss of emergency containment cooling was interpreted to mean total loss of core cooling. Reports about wind direction also cause problems, because there are different ways of expressing wind direction. Radiation data may also arrive in different forms, and require translation.

These observations point to an information management problem in the emergency organisation. Specifically, difficulties are caused by delays and problems in interpreting information. Some of these problems should be, if not eliminated, then at least alleviated by faster and more reliable forms of communication in a standard format to insure that all necessary information was included and in a form that could be understood.

3. CONCEPTUAL WORK

The conceptual work started from the assumption that the problem was to design a general system to be used for many different kinds of emergencies. This led to the question of what aspects could be common to different emergencies, and whether there was any form of organisation that would be useful for each of these.

The literature (e.g., Dynes, 1974) suggested that emergency organisations generally followed a military hierarchical command and control structure, but that such an organisation might not be suited for all aspects of emergency management. Specifically, the results from many studies of behaviour in emergencies suggested that a community would exhibit various forms of self-organisation, and that a military style command and control structure may not be the whole answer to the emergency management problem. However, it was not clear which aspects of the total emergency management could be left to self-organising forces, and which would have to be carried out by some existing organisation.

These considerations led to work in three different directions:

- an analysis of the nature and limitations of hierarchical command and control systems

- an analysis of distributed decision making.

- an analysis of emergency management in an attempt to find a general theoretical structure for emergency management.

3.1 The nature and limitations of hierarchical systems

The results of the analysis of hierarchical systems (Brehmer, 1988) suggest that such forms of organisation are useful for two different purposes: (1) regulating the complexity of the decision problems encountered in an organisation and (2) for coping with tasks where one has to consider different time scales, or spatial scales. The military hierarchical organisation is an example of an organisation that capitalises on both of these strengths of a hierarchical organisation. Thus, the division into units at different levels regulates complexity: a company commander has to consider a limited number of platoons, and a battalion commander a limited number of companies, and so on. Moreover, a company commander would have to cope with a smaller area than the battalion commander, i.e., the different levels in a military hierarchy have to consider different scales.

Whether a hierarchical system will function well depends on the extent to which it actually regulates complexity, the extent to which different levels in the hierarchy can be tied to different scales, and the extent to which communication between levels in the form of goals fed from higher levels to lower, and feedback fed from lower levels upwards, functions well. Because processing of information at each level and communication between levels takes time, hierarchical organisations tend to function best under conditions where the environment is predictable and the demands for fast responding and reorganisation are small. This makes them less suited on the management of unknown emergencies, and a general organisation for emergency management must therefore be built on different principles and involve forms of distributed decision making.

3.2 Analysis of distributed decision making

The general problem facing an organisation characterised by distributed decision making is that of co-ordination of different decision makers who have limited and at best partially overlapping models of the problem. Moreover, this co-ordination must take place under dynamic conditions, where the state of the system changes both autonomously and as a consequence of the decision makers' actions. This is a new research topic and very little is known about what kinds of organisation or communication patterns will prove effective under such conditions.

A review of the literature (Brehmer, 1989a) yielded little information of use. Most research of relevance for the problem has been carried out in the area of distributed artificial intelligence. This research provides some useful concepts, but some of the problems analysed are of little relevance. For example, in distributed artificial intelligence, it is an important goal to keep down the need for communication, since the costs of communication tend to be high relative to those of computation. However, in distributed decision making, the problem is rather to increase the possibilities for communication.

Brehmer (1988) and Rasmussen (1986a) have analysed different architectures of distributed decision making and how these might function under different circumstances. One problem here is how a distributed organisation could cope with problems involving different time scales. This problem seems to require a hierarchical organisation, for in this case distributed decision making without overall control may lead to local optimisation with long term catastrophes as a consequence.

The analysis of distributed decision making is, however, only in its infancy, but the NKA/INF project has provided a starting point for such work which is now carried on in a Esprit II BRA project "Mohawc" (ESPRIT 3105).

3.3 A general theoretical structure for emergency management.

Work here has followed a control theoretic approach (Brehmer, 1989b). Emergency management has been defined as a control system designed to control the number of injuries/deaths in society. To do so effectively, a feedforward strategy is required, which can detect possible emergencies and correct for them before they occur. This in turn requires a general detection system which monitors possible emergencies, and a general diagnosis system for diagnosing these emergencies. Neither of these exist today, except for more limited forms of emergencies.

The actual management of emergencies can be analysed in terms of Rasmussen's (1986b) abstraction hierarchy (Brehmer, 1989b). Two abstract functions: injury/damage control and relief operations were suggested. The injury/damage control abstract function was then analysed in terms of three generalised functions for emergency management: to remove the source of danger, to raise barriers between people and the danger, and to remove people from the danger. These three generalised functions then take somewhat different forms, depending on the type of emergency. In the case of a nuclear emergency, removing the danger corresponds to successful attempts to stop or contain the radiation at the plant, creating a barrier might be to recommend the intake of iodine pills, and an example of removing the people would be evacuation.

The county EOC has to make its decisions at the level of these generalised functions. Consequently, decision support must be developed to aid these particular kinds of decisions. Time-area diagrams which show the predicted spread of radiation, as well as the predicted course of evacuation, could provide such support. When what spreads spreads among persons, rather than over some area, the diagram would, of course, be a time-person diagram instead.

Figure 3.1 gives an example of such a time-person diagram for a particular form of emergency, that of an epidemic. The disease spreads quadratically, but the means to combat it - vaccination - works linearly (because one can only vaccinate a given number of people per unit time). The diagram gives the general condition for success in controlling the epidemic: it is to start vaccination so that it has been completed before the disease function intersects the vaccination function.

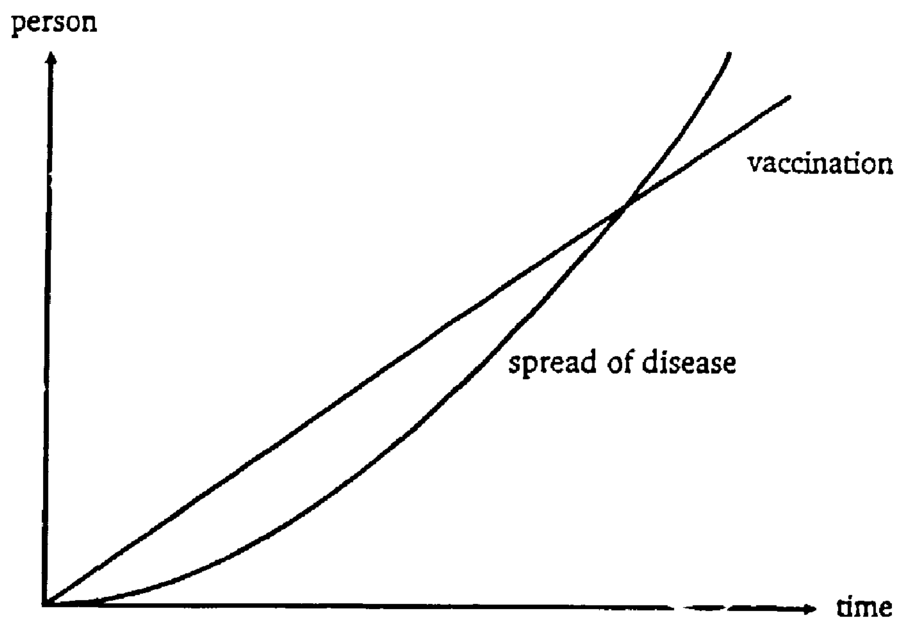


Figure 3.1. A time-person diagram for the problem of fighting epidemics using vaccination.

Similar time-area diagrams can be constructed for all emergencies that spread over area or within a population, and they make it possible to decide first, whether a given action may succeed, and second, when the action has to be taken to succeed. Thus, we might design such diagrams for fires and fire fighting, the spread of radiation and the rate of evacuation, or the rate at which people take their iodine tablets, and so on. In all these cases, it is not a problem to decide which action should be taken. The problem is to decide when the action should be taken. Representations of this kind should be useful in supporting the decision about timing of actions.

4. DEVELOPMENT IN INFORMATION TECHNOLOGY

4.1 Technology trends

Use of information technology has increased drastically over the last decade. In all fields of technical, economical, financial, and administrative matters, computer systems have become an integral part of the work routines. Almost everybody has access to a computer terminal. In everyday life people experience this, e.g., in bank services where summaries of their accounts and payments are done via computer terminals. In summary, this is of benefit to most people and has lead to an overall increased productivity, but it also shows how vulnerable our society has become due to this technology in case of computer system breakdowns. This must be kept in mind when applying this technology in emergency management.

The recent advances in information technology might be classified into three areas: 1) computer hardware, 2) networking and 3) computer software.

1) First of all the computers have improved in cost/performance. The price of computers is no longer a major concern. Instead of centralised big computers one gets small personal computers or workstations distributed where needed in an organisation.

2) A network between computers which simplifies information exchange, e.g., in the form of "electronic mail", is easily obtained at low price .

3) Software is probably the area where advances are most welcome in the future. However, user friendly systems are developed and applied in a number of disciplines.

Advances in all these three areas are important for efficient use of information technology in emergency management. Networking capabilities are especially important for exchanging information in large emergency organisations. Here, we will concentrate on the latest software tools to see how they can be applied to emergency management.

4.2 Advances in application of artificial intelligence and expert system techniques

The continuous development of software systems and, in particular, the possibilities offered by artificial intelligence with new symbolic languages has made the development of new information and decision support systems attractive. Expert systems is a branch of artificial intelligence which has evolved over the last years. These systems can contain specialised problem solving techniques and expert knowledge within a particular application domain. Specific features of these systems, in contrast to conventional data processing systems, are their symbolic inference, which is supposed to be closer to the way an expert reasons and expresses his views about a problem area.

One of the technologies offered by Artificial Intelligence is an integrated development environment on dedicated workstations, e.g. Lisp computers, which facilitate incremental system development. Lisp computers offer a software environment with several tools and implementation techniques for expert system applications. The problem is often to choose the best way of implementation among many possible alternatives.

The investigation of these techniques and application of them in various aspects of emergency management was the purpose of this joint Nordic project. In case of an emergency there will be a number of experts in different problem domains with varying background and position in the organisation. This means that a computerised system must support a wide variety of functions including exchange of information between different user groups. No single tool exists for such a diverse application and different implementation strategies will be discussed when describing the prototype.

4.3 Review of typical applications of new technology in process industry

In the initial phase of the INF project a literature survey (Berg & Yokobayashi, 1985) was made of the various activities in development of computerised support systems to assist in emergency situations. One such system is developed for the

Technical Advisory Body (ETAB) in Japan (Kobayashi, Fujiki, Kohsaka & Ishikawa, 1985) for managing a great number of documents with information about nuclear power plants and assist in fast retrieval of critical information. It will also support technical experts with diagnosis, status assessment and prediction of radioactive release in order to plan the evacuation of people in critical areas.

Another Integrated Emergency Management System (IEMIS) has been developed in the USA (Jaske, 1985) for the planning, exercising and real-time management of accident and disaster response. Decision making is assisted by a set of simulation models involving dose estimation and diffusion from containment to air and water. It comprises also simulation of various evacuation options integrated with a national map and geographic information system.

From non-nuclear industry one can mention the MannTall system (Honne, 1987) which is used in offshore catastrophes to determine whereabouts of missing persons during large-scale rescue operations.

In the last year a number of systems and prototypes have been reported and several of them are described in detail in the ISEM project (ESPRIT 2322).

4.4 Potentials of new information technology.

In a large organisation, as that described in the previous chapter, it is obvious that computer networks can assist in keeping the various parts of the emergency organisation informed and updated about the overall status in case of an accident. Delays are minimised and broadcast of important information can be made by decision makers. Further, computer systems can be used to reduce the problem of information overload by offering the user tools for accessing and filtering data.

In almost every part of the organisation procedures there are check lists which detail what should be done in case of an emergency. Computerisation of procedures are one obvious way of utilising new technology and a system has been developed to support on-site personnel (Öwre, 1987).

Another application is to support people with diagnostic tasks. Recently an experiment was conducted at the OECD Halden Reactor Project to assess the effectiveness of the diagnosis expert system DISKET (Diagnosis System Using Knowledge Engineering Technique) for helping reactor operators diagnose and treat malfunctions (Holmström, et al., 1989). The experiment clearly showed improvement in performance in the measures related to the treatment of the transient malfunctions. This is a very significant result, and suggests that diagnosis systems such as DISKET may provide significant assistance for nuclear reactor operators.

Can these results be extrapolated to emergency situations? It is certainly important for on-site personnel to know the precursor of an accident better. However, major problems still exist in situations where no procedures or diagnostic rules are available. The user must be aware of the limited scope of the support systems to avoid situations where he is looking for a non-existing procedure or diagnostic rule to apply. Assistance in unforeseen situations is a growing research area in AI. Use of deep knowledge models where the physical behaviour of systems are described together with the expert rules will improve the robustness.

A system which advises operators in severe accidents is the SPMS, Success Path Monitoring System, (Baker, 1988) which aims to provide an on-line assessment of both the status of critical safety functions and the status of success paths for correcting the threat to the critical functions in a plant. The experimental evaluation concluded with quite distinct advantages in speed and accuracy of operator performance in taking corrective actions.

The support systems mentioned in this section have not been applied in the current NKA/INF prototype system, but should be mentioned as candidates for application in future emergency management systems.

5. PARTICULAR SYSTEMS SPECIFICATION

The emergency organisation comprises a number of on-site and off-site Emergency Operation Centres (EOCs). A picture of this organisation in Sweden is given in Figure 2.1. It illustrates the flow of information between various EOCs in emergency situations. As can be seen from the figure, there is a number of active groups requesting different information from a multitude of sources. The on-site people mainly focus on the plant itself, concentrating on accident mitigation and performing the recommended actions. The off-site part of the organisation deals with the possible danger of radioactive release to the environment and possible evacuation of people if necessary.

In order to specify a Decision Support System (DSS) in this environment, the functions and tasks for each EOC must be specified as well as the communication paths between the centres. The following check-list was applied for each EOC:

- main tasks
- subtasks
- data received
- data generated
- data sent
- desired functions of a DSS
- needs for status and global overview
- particular expert knowledge possessed by the centre

The results of this analysis are described in Berg, et al. (1987) and summarised in this chapter.

5.1 On-site system specification

5.1.1 Requirements

During emergencies the people acting in emergency organisations have to look at the plant from points of view that differ from those used during normal plant operation. There are four main areas of information to be dealt with during an emergency. These are accident, radiation, actions, and organisations/communication to the off-site environment. There is also a corresponding division of responsibilities in the preparedness organisation. The shift supervisor and the plant operations manager takes care of the process and the accident. The radiation protection manager is responsible for radiation protection and all kinds of matters concerning radiation, releases, doses etc. The maintenance manager takes care of what happens on-site, outside the control-room. The contact persons to the nuclear power authorities and to the off-site EOC take care of informing the off-site authorities.

The plant emergency manager has the overall responsibility for co-ordination and management of the on-site organisation.

When an accident has occurred at a nuclear power plant the most important questions to be asked are

- What has happened?
- How will the accident proceed?
- How can the plant be brought to a safe state?
- What kind of help is needed?
- Does the accident cause danger to people, how great is the danger, to whom and when?

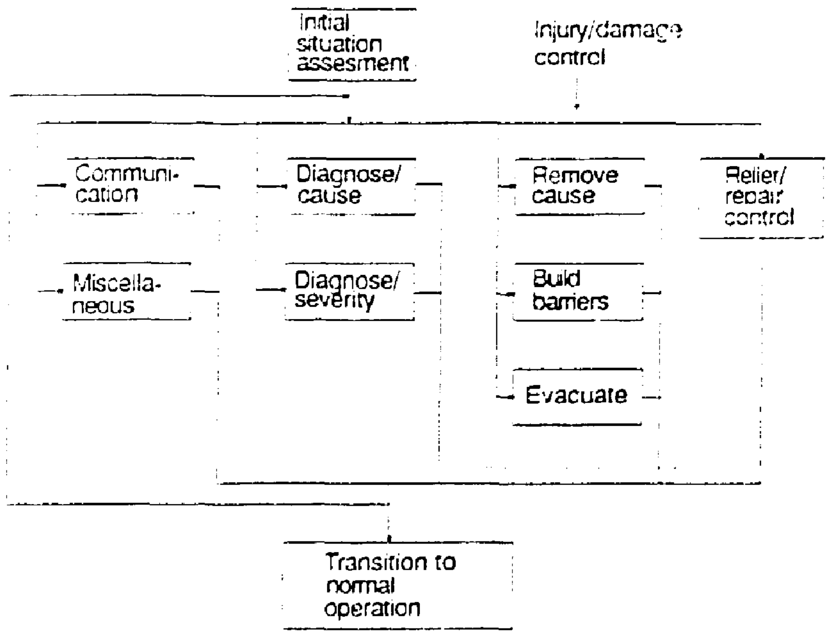


Figure 5.1. The main tasks of the on-site emergency organisation.

The emergency management system should support decision making on these matters.

The activities of the on-site emergency organisation is schematically represented in Figure 5.1. The tasks are executed in parallel and repeatedly. The plant emergency manager should, nevertheless, have a good overview of what is going on.

Decision making connects diagnosis to the damage and injury control, which is an important part of the activities, because tasks in this area do not belong to the normal routine of the plant. Relief and repair control does not need special support, because repair work, for example, is part of the normal on-site activities.

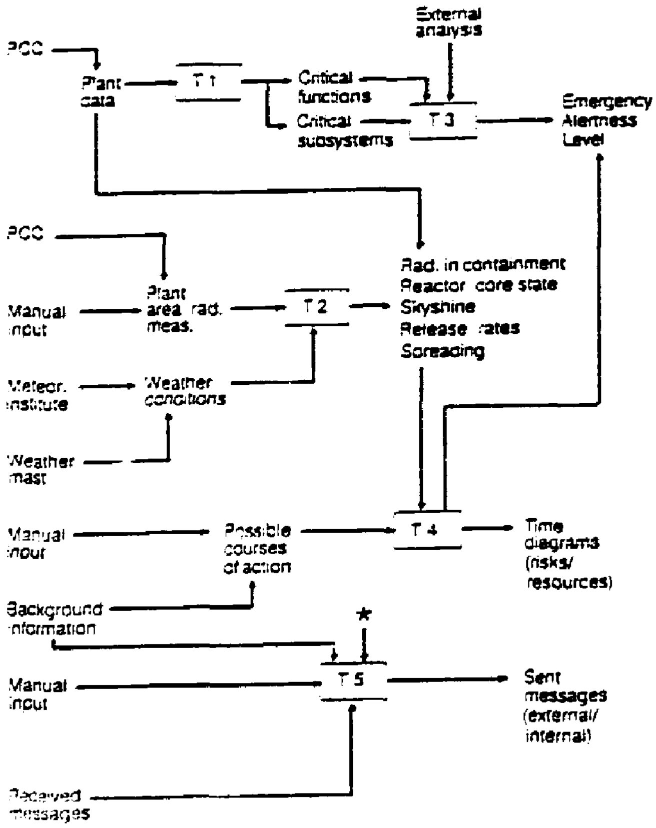


Figure 5.2. The use of data and knowledge in on-site emergency management (PCC=Process Control Computer). The boxes represent data transformations. The transformations T1 to T5 are explained in the text. The star sign (*) depicts inputs from all data items in the figure, e.g. critical functions, time diagrams etc.

Figure 5.2 represents the flow of information in on-site emergency management. Physical level data (on the left hand side in the figure) are transformed into information on higher levels of abstraction as a basis for decision making and (external) communication.

Without an integrated computerised support system these transformations are made manually, with separate and specific computer tools, and sometimes even implicitly, i.e. the concepts "emergency alertness level" and "time diagrams" are only in the mind of the plant emergency manager. The transformations in the figure can be described as follows:

- T1 represents the process of combining the process data in a way which expresses whether some of the critical functions are jeopardised or not. Examples of critical functions are Reactivity control, Reactor core heat removal, and Reactor coolant system inventory. Critical subsystems represent a measure of to which degree a certain subsystem of the plant is available.

- T2 depicts radiation calculation/prediction methods. The contents of this box is basically what the radiation protection manager is doing.

- T3 copes with external analysis input of whatever analysis methods available, such as nuclear plant analysers. Plant and radiation data are combined to form a measure of the emergency alertness level. This is largely the task of the plant operation manager and the operation group.

- T4 accomplishes an evaluation of the possibilities in the situation at hand. The input is situation analyses and alternative courses of action to cope with the situation.

- T5 represents the fusion of all available information. The output is communication, both internal and external, with information to be used as a decision basis, directives, commands etc.

The transformations should be made explicit, because they in a way represent the general strategy to deal with the emergency. The information contents of the support system should also be organised so that the general strategy is explicit all the time. The man-support system interaction should happen in two ways, (1) manual input of data, such as measurements and external analyses, and (2) control of transformations.

Apart from the functions that actually have been implemented (as described in the prototype implementation section) some other functions would be very useful:

- layered maps: Maps which can be scaled and panned. Different features can be superimposed on the maps: infrastructure, demographic data, topographical data, radiation measurement data, prognosis for spreading including e.g. isodose and isodose rate lines.

- document databases: plant documents, operation documents.

- emergency alertness level assessment: provides information about the state of the nuclear power plant on a high level of abstraction. It provides, in principle, a strictly limited measure of the danger of the situation and monitoring of drastic safety related changes of the situation.

- resource supervision such as personnel, physical accident fighting resources etc.

5.1.2 Data and knowledge bases

Items to be included in the data and knowledge bases are the following:

- process data to a limited extent: measurements, alarms, critical functions, state data from the process computer,
- layered maps,
- local weather condition data,
- measurement stations and measuring routes for patrols, including all attributes,
- laboratory analysis data of samples,

- emergency operation guidelines,
- message base,
- reports and text data,
- log book including decisions and measures, actions taken,
- computational algorithms,
- success criteria for the critical safety functions.

5.1.3 User interface

The task of the plant emergency manager is to be in charge of the emergency operations and not to interact with computers.

As a consequence a full scale emergency support system should be an easy to use source of information. Therefore WIMP (windows, icons, menus, and pointing) interface techniques must be used. The role of the system is to advice, guide, and call attention to things.

Except the normal user interfaces also other interfaces must be provided, like connection to the process computer, maintenance, external data input, and training interfaces.

5.2 Off-site system specification

This section is concerned with a specification for the County Emergency Operations Centre (CEOC) as it exists in one county in Sweden, since the system was implemented and tested in that environment. This organisation may be unique in some respects, and the present specification may therefore not apply to other countries, or even to other counties in Sweden.

5.2.1 Background

According to Swedish law, the County Board in counties with nuclear power plants are responsible for emergency planning in the case of a nuclear accident. Emergency plans have been prepared in consultation with competent authorities for radiation protection (SSI) and nuclear safety (SKI), with local authorities and with the nuclear power plant.

The County Board reports directly to the government, but is autonomous within its sphere of authority.

5.2.2 The County Board Emergency Organisation

In the case of a nuclear accident, a County Board Emergency Organisation (CEOC) is activated, see Fig. 5.3. The emergency organisation in Fig. 5.3 is presently under revision due to new national laws pertaining to emergency preparedness and emergency organisations. However, major changes in the emergency organisation are not foreseen. The organisation shown in Fig. 5.3 has been subject to a number of drills, and analyses of the results from such drills form the general background for the systems tested in this reported.

The CEOC follows a general emergency plan. This plan contains

- Alarm functions
- Information to the public
- Issuing of iodine tablets to the public
- Protective measures, such as evacuation
- Measurement of radiation levels

The area surrounding the nuclear power plant is divided into an emergency zone and a measurement zone. Within the emergency zone, there are highly detailed plans for

- Alarming the public with automatic technical systems
- Immediate intake of iodine tablets in case of a radioactive release. Iodine tablets have been distributed.
- Evacuation
- Written information to the public

Within an area outside the power plant, the measurement zone, measurements of radiation levels will be performed by the fire department which reports to the CEOC.

One of the CEOC:s staff members is assigned the role of acting Emergency officer. S/he initiates immediate actions upon alarm that a nuclear accident has happened or is likely to happen. Separate plans are prepared for different levels of emergency. Other parts of the emergency organisation are alerted. The aim is to have the full organisation in operation within 2 hr.

SSI and SKI are the main advisory bodies.

As the accident proceeds, and when a decision on protective action is taken, numerous contacts will take place with all organisations and authorities involved in the emergency plan, as well as with agencies not included in the plan. The public will demand continuous information.

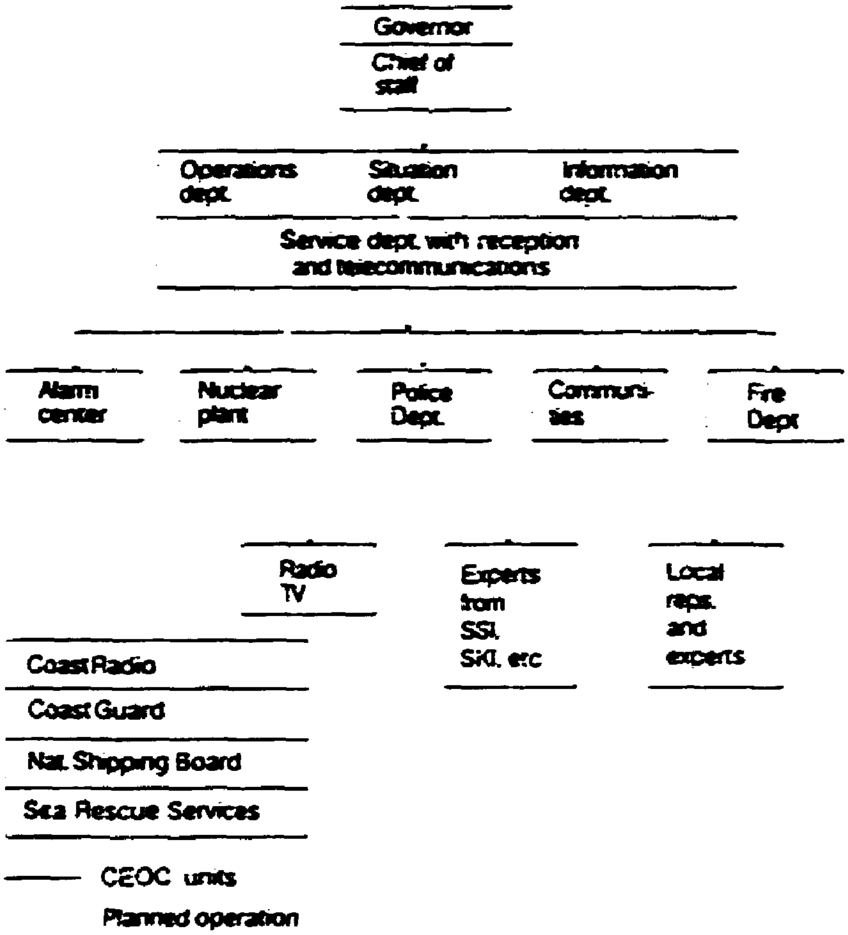


Figure 5.3 Organisation of the County Emergency Organisation Centre (CEOC).

5.2.3 Requirements on an information system

In case of a nuclear accident, the CEOC will need information on

- what happened,
- has there been a release of radioactive substances, or is such a release likely to occur,
- weather conditions: rain, wind speed and direction, temperature,
- actions taken on the site
- data on radiation levels as measured by the plant, the fire brigade, or SSI
- prognosis concerning the development of the accident

In addition, information to and from various authorities, organisations, and to the public has to be issued and received.

Information will reach the CEOC from the plant, SSI and SKI, as well as from other central and local authorities and from the various units of the emergency organisation. As the emergency progresses, the amount of information will be considerable.

The information system should assist the CEOC in obtaining an up to date, clear picture of the overall situation. Such a picture is of utmost importance for making adequate decisions both in the emergency organisation and with respect to protective actions. A continuously updated picture should be available to all parts of the emergency organisation.

In an emergency organisation, there will be great pressure upon the information department in the CEOC. The public will demand the latest information about radiation levels, protective actions and the general situation at the plant. Good operational control of the emergency is a prerequisite for good functioning of the information department.

The information system should register when information has reached the CEOC, the sender, and the content of the information. In that way, the information system should support decision making activities and that no actions are overlooked. Decisions and actions to be taken are those specified in the plan. The system should register when a decision or action has been performed and store the content. Recall of information or decisions should be possible at any time.

In addition, the system should provide sorting functions (sender, urgency, keywords, and topics) to track information received or issued.

5.2.4 User interface

The task of the emergency office of the CEOC is complex and demanding. The computer systems should be user friendly, and guide, advice and call attention to actions.

The system should be available to all units of the CEOC so that each member of the centre has access to the same information. Preferably, authorities outside the CEOC should also have the information and communication via special communication lines. In particular, connections should be arranged with SKI and SSI.

5.2.5 The prototype system

The prototype system can only test some of the functions mentioned above. The most important functions in the prototype system are the message system and the logging and reminder functions in the form of the emergency preparedness guide.

6. PROTOTYPE IMPLEMENTATION

It was never the intention to make a complete prototype for the full on-site and off-site organisation within the scope of NKA/INF. Instead, it focused on two key nodes in the organisation: the on-site Plant Emergency Manager and the chief of the off-site County EOC. The two prototypes implemented for the on-site and off-site users have approximately the same functionality. Only some minor aspects differ. The differences are due to the different environments where the support systems are to be used. An example of this is the different set of categories supplied for messages to be sent.

Prototyping was done on Symbolics computers utilising the Lisp environment with object oriented programming techniques. The on-site system was made by VTT, Finland while IFE, Norway implemented the off-site system. Common functions in these two prototypes were exchanged between the two partners to avoid duplication of work.

The particular system functions developed reflect the needs identified during system requirement specification. Three major functions are included: 1) Preparedness guide, 2) Reminder and 3) Message handling.

1) In most centres a set of written procedures has been prepared to guide people in emergency management, especially in the initial phase. The emergency preparedness guide is implemented almost in its original form and from a momentary menu one can choose what section to look at. As one proceeds down the procedure, there is space available for making time stamps and writing comments.

2) The reminder function is a way for the decision maker to make sure that he/she will remember important duties as an emergency develops. These duties may, for instance, involve sending status reports every half hour, or checking that important tasks have been carried out as ordered. In addition the decision maker can make use of this function to input important things he will be reminded about later on.

3) The message handling system is developed to support decision

makers with the large amount of information exchanged during emergencies. Information overflow, misinterpretations, inconsistencies, and prioritization are typical problems encountered during emergency drills.

The other functions described below are auxiliary or special features required for the two particular interfaces implemented, i.e., that for the plant emergency manager and that for the chief of the county EOC.

6.1 Basic man-machine principles

The man-machine interface is a key part of this decision support system serving a number of people with different background and needs. This type of system will not be in daily use, so the screen layouts and dialogue features should be made as self-explanatory and informative as possible. Mouse sensitive items in window systems and fixed or momentary context related menus offered by modern workstations have been utilised to accomplish this goal.

A typical way of interaction between the user and the system follows the pattern shown in the figure below.

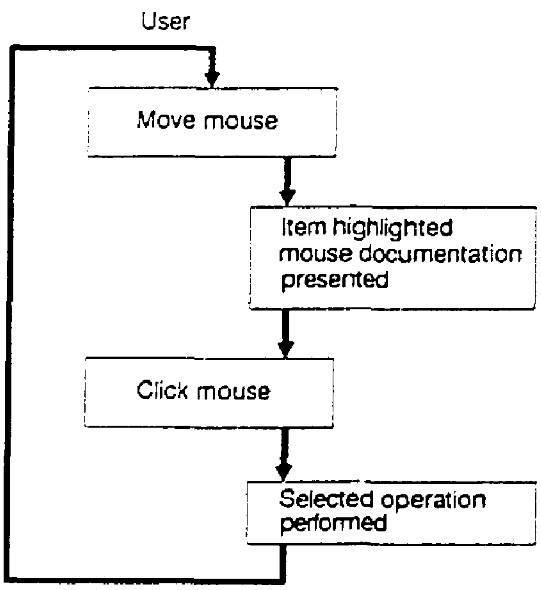


Figure 6.1 Mouse operation

- Mouse

On the screen there is a mouse symbol shown as an arrow. When the mouse device is moved, the position of the mouse symbol on the screen will change correspondingly.

When the mouse symbol is placed on a command field, the field will be highlighted, i.e., a rectangular box will be displayed around the text. The fact that a field is highlighted means that a command can be executed. The mouse device has three push-buttons on top of it, which are used for giving commands. Possible mouse actions are always listed in the mouse documentation line on the screen and will give additional information to the user.

- Screen

The screen consists of a set of smaller windows, which are called panes. The general layout is shown in Figure 6.2. This picture can always be displayed by clicking at the text in the top level menu. From this picture you can select message handling, phone directory, preparedness guide and the reminder function. When needed, the user is asked to input text in special panes.

Other aspects of the man machine interface can be summarised as follows:

1) Feedback on mouse clicks:
   In some cases, when a mouse sensitive item has been clicked, immediate feedback on the command is given. The item may change from inverse video to normal background colour (the command field is changed to white text on a black background).

2) Pop-up windows:
   A pop-up window is a window which is not part of the permanent screen, but "pops up" over the other windows in special cases, like the reminding function.

6.2 Particular System Functions

6.2.1 Preparedness guide

The preparedness guide is a computerised form of the actions which the user of the support system is supposed to perform, or more concretely the procedures to be found in the preparedness plan.

On the far right hand side of the screen (Figure 6.2) there is a pane labelled "Items in preparedness guide". The contents of this pane is a list of numbers indicating the procedures that have not yet been successfully performed. The rest of the screen displays the procedures and possible documentation. Space is left for comments and time-stamping.

The procedures are mouse sensitive and by clicking on them a small menu pops up. The choices are "Task performed" and "Did not succeed". By choosing one of these a time stamp is printed on the screen. If the task is indicated performed, the number of the task disappears from the "Items in preparedness guide" pane on the far right hand side and the black box on the number of the procedure disappears as an indication of successful action. Comments on the procedures can be inserted if needed.

Some of the procedures contain separate mouse sensitive items in bold face. These are items that have special documentation available. By clicking on one of them the corresponding documentation is printed on the lower part of the screen.

All of the procedures cannot be shown on the screen at the same time, because the list is too long. To get more procedures one can either click on the scroll bar in the guide-pane or click on the number of one of the procedures in the "Items in preparedness guide" pane.

If some of the procedures need to be performed repeatedly the "Reminder" command can be used to help the user remember this, see below.

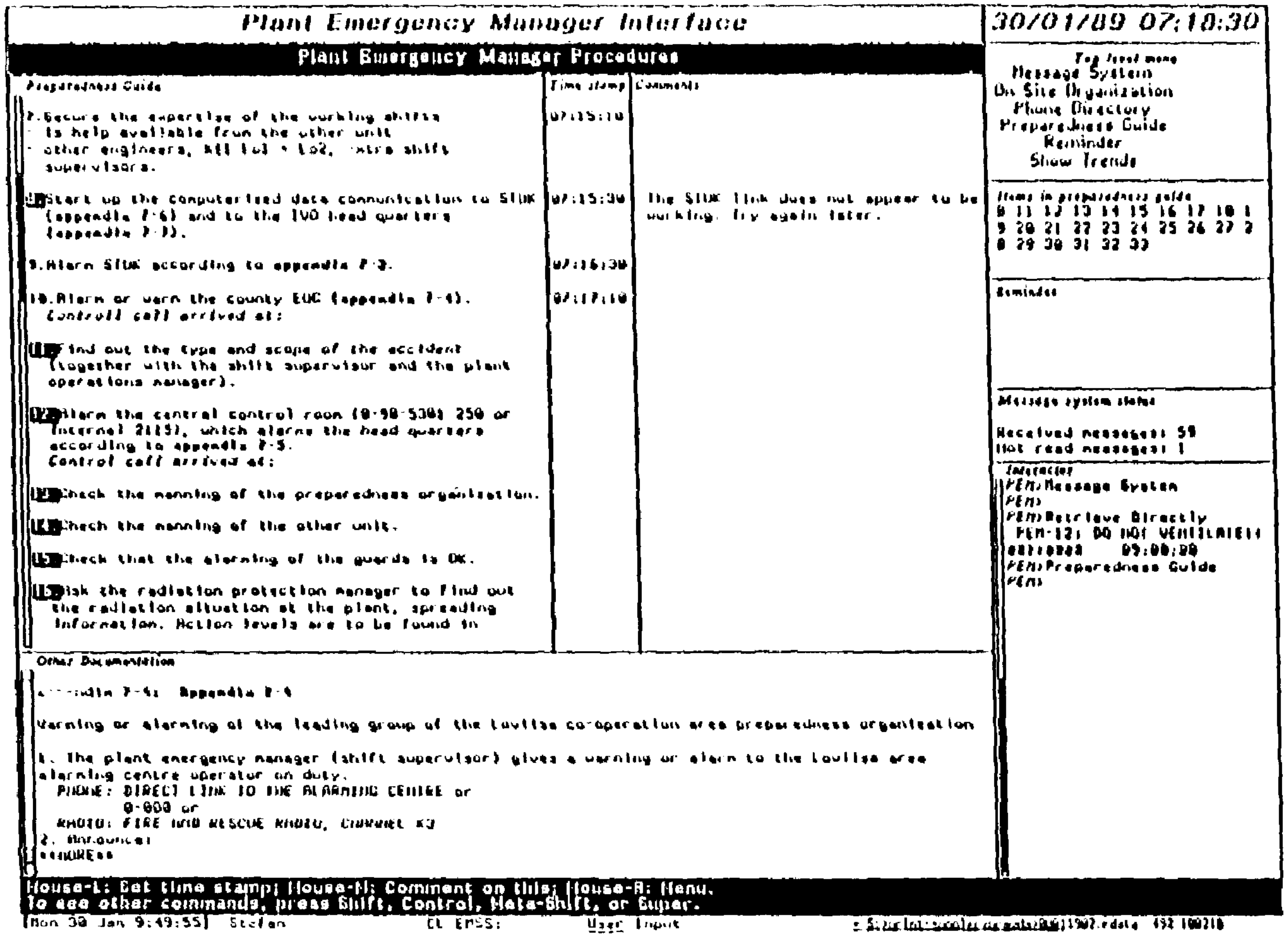


Figure 6.2 Screen layout when working with the preparedness guide.

6.2.2 Message handling

The message handling function is particularly adapted for emergency management applications. It makes it possible to send messages to a pre-specified set of centres equipped with the same kind of support system that the sender has.

Two layouts of the screen are used for the message handling system. One is used for writing messages, the other for reading messages and other functions (see Figure 6.3). The column in the middle, consisting of two panes, shows the "current message", i.e., the message on which all actions, except writing, are performed.

The column to the left is labelled "Message handling" and consists of five panes. The first of these shows a record of messages that have been received, the second a record of messages that have been written by the user. Messages received, but not read, and messages written, but not sent, are shown in inverse video. The third pane shows a menu to be used for sorting parameter selection. The last two panes display sort keys and sorted messages.

When a message arrives, a small window pops up under the mouse blinker. The content of the window gives information about the sender and the name of the message.

In the column to the right, which is the same in all layouts, a small pane labelled "Message system status" shows two pieces of information: number of messages received and number of messages which have not been read. This information is always kept up to date.

Each message has a number of attributes, such as code, name, time created, time sent, time read, sender's name and position, receiver's name and position, category, priority and topic. All of these do not necessarily have to be used, but some are, however, compulsory. A short description of the attributes is given below.

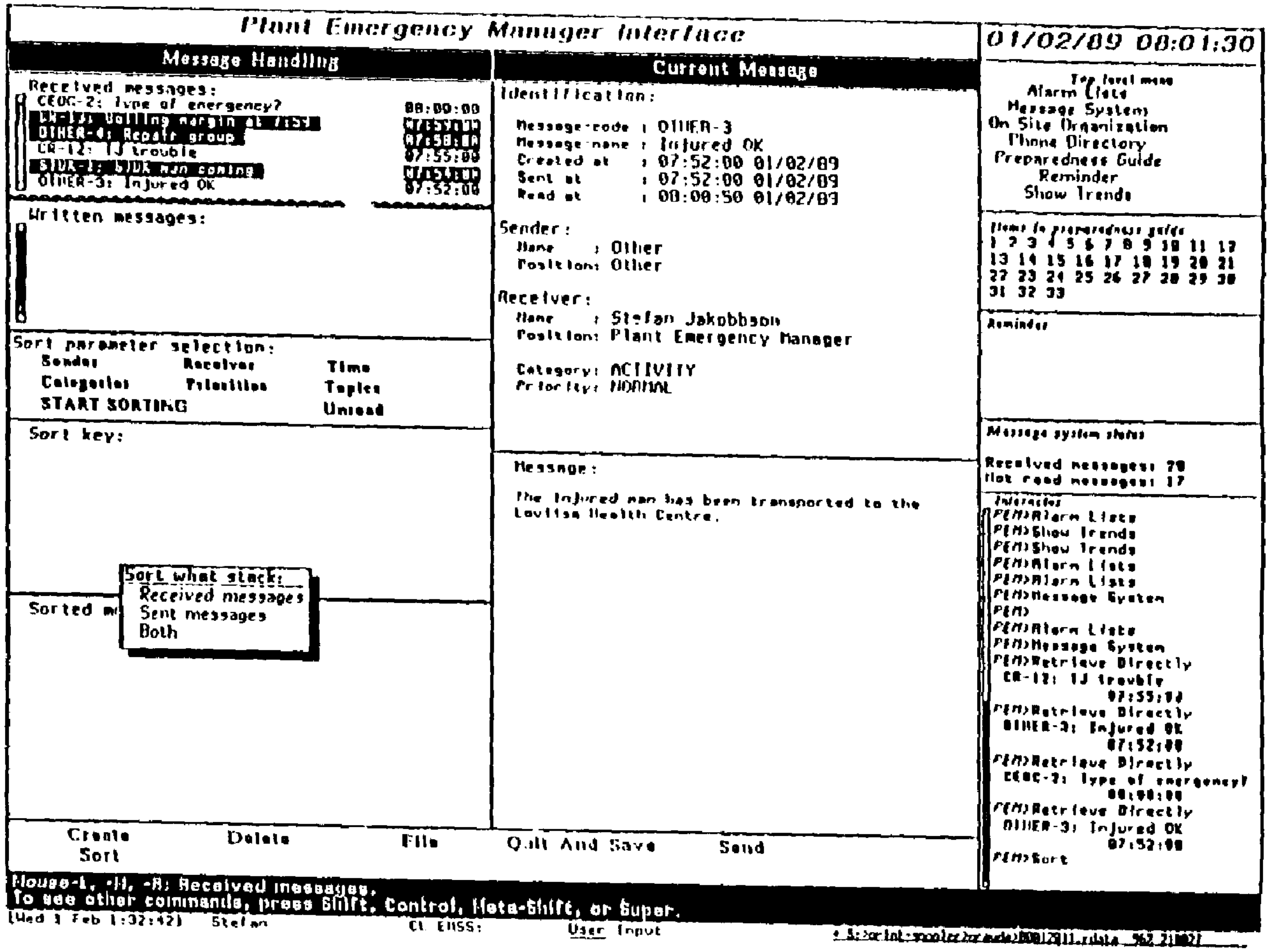


Figure 6.3 Screen layout for message handling.

- code	tells who the sender is and how many messages he has sent. Thus, the code PEM-4 is the code for the fourth message from the plant emergency manager.
- name	a short description of the contents of the message in the form of a headline
- time stamps	created automatically
- sender name	supplied automatically
- sender position	supplied automatically
- receiver name	supplied automatically when a message is answered, otherwise optional
- receiver position	supplied automatically when answering a message, must otherwise be supplied
- priority	compulsory, with categories "urgent", "normal", "low"
- category	compulsory, one or more from a pre-specified set
- topic	a means for organising messages according to topics that the user can specify. It will not be sent but is used for sorting messages.

6.2.3 Reminder function

The reminder command allows the user to input texts that have to be remembered either at certain points in time or repeatedly. When you enter the reminder function in the top level menu, the window shown below is displayed.

You place the cursor at 'string' and input your own text. Then enter when (how many hours and minutes from present time) the reminder should appear. You may also choose to have the reminder appearing several times, at intervals. In that case another menu will appear, and time interval in hours and minutes has to be specified.

Remind user input	
What to remind: ' string ' How many hours from now: 0 How many minutes from now: 1 Reminded more than once: No Yes	
done	abort

Specify remind interval	
Repeat interval in hours: 0 Repeat interval in minutes: 5	
done	abort

While you are performing other tasks, the reminder display will appear on the screen at the point where the cursor happen to be located at the time of reminding, like all other pop-up menus. When removed, by moving cursor, it will reappear in the reminder field on the screen. By placing the cursor in this field, you can have a look at the message again.

6.2.4 Phone directory

Phone directories with numbers to all organisations active in emergency management is included. The directories can be searched through to find numbers according to name and position of people and organisations.

6.2.5 Alarm lists

The "Alarm Lists" command provides lists of people to be alarmed for different positions in the preparedness organisation. The "On-site Organisation" command also provides support for setting up the preparedness organisation on-site.

6.2.6 Trend displays

Trend displays for the most important process and environment parameters are provided on-site. Five different trends or bar charts can be shown at a time.

6.3 On-Site system

6.3.1 User interface

The implementation is structured in a top-down manner with the user interface on top. Below this is a number of independent modularly implemented functions. The user interface makes use of a large number of special non-standard extensions to Common Lisp. This was necessary to make it as user-friendly as possible, but the cost is lack of portability. The prototype system can without modifications be used solely on Symbolics machines. Common Lisp as such does not support the construction of WIMP interfaces (Windows, Icons, Menus and Pointing).

The user interface is mouse and menu driven. The keyboard is needed only for a few operations, such as typing messages or comments on items in the preparedness guide.

6.3.2 Scenario implementation (SCEDLA)

A SCEnario Description LAnguage (SCEDLA) allowing for "simulation" of events and processes has been developed. SCEDLA enables description of scenarios using a high level description language. The intention of 'scenario description' is to prespecify messages to be sent at certain time points and the 'simulation' of process and radiation parameters. This is a useful facility for training and evaluation purposes. A facility to make the pre-specified scenario branch according to what actions the user takes is also included, although it has not been actively used in the tests.

Functions, which have been (partly) specified but not implemented include

- maps and state displays showing radiation levels etc. (the basic maps are actually implemented but without the needed dynamic features)
- EAL (Emergency Alertness Level) system keeping track of action levels, resources, etc.
- predictive functions
- inclusion of radiation calculation software
- critical function and subsystem monitoring

6.4 Off-site system

The off-site system is designed to support the chief of the County Emergency Operation Centre (CEOC) in Uppsala, Sweden. Background information was extracted from their current handbook. The three basic procedures (information, warning, alarm) ranged according to severity, were implemented in the preparedness guide. All phone lists were included and grouped according to the classification in the handbook. The message system was initialised with data on sites and organisations in Uppsala and Sweden. Operation of the interface and details of particular functions are described in previous sections.

6.4.1 Off-Site scenario implementation

The scenario consists of a number of messages which are sent to the test subject (chief of CEOC) at defined time points. The experimenter used a workstation with almost the same features as the CEOC configuration to store the messages used in the scenario. By utilising the facilities of the message system, the experimenter could write, edit and delete messages as desired. A few extra functions were developed for the experimenter. For instance, one can easily choose among different scenarios, initialise scenario time and make hard copy for documentation.

Two Symbolics computers were connected to each other via an Ethernet cable. One of them was located in an experimental control room at IFE, Halden, where the test subject (head of CEOC) could read information from the system. When inputting data and sending messages the subject was assisted by a terminal operator familiar with the functions of the system.

The other computer was placed in the room next door to simulate the "outside world", which means the rest of the emergency organisation. The outside world was in reality the experimenter sending messages defined in the scenario. In addition the experimenter had to answer any question raised by the test subject via messages to the outside world.

An equivalent installation was made in Uppsala to carry out part of the experiments.

7. EMPIRICAL EVALUATION OF THE PROTOTYPE SYSTEM

7.1 General considerations

In actual practice, it has proved difficult to evaluate information systems and decision support systems in full scale tests. Indeed, with some exceptions (e.g., Baker, et al., 1988; Holmström, et al., 1989) most full scale evaluations show no effects of the information or decision support system. This is hardly surprising: a given system can at best help with some small part of the total decision task, and there is no guarantee that this particular part will prove decisive in a given full scale evaluation.

Because of this difficulty, attempts to find alternatives have been made. One such alternative method proposed by Rouse and his associates (undated) is called conceptual evaluation.

A conceptual evaluation does not involve any empirical test of the system. Instead, the capabilities built into the system are compared with the demands as assessed in some analysis of the task. If there is a match between the capabilities and functions built into the system and the demands made by the task, the system passes the conceptual evaluation. Even though the method as proposed by Rouse, et al. is quite detailed and explicit, in the final analysis it nevertheless rests on judgement, and the results of a conceptual evaluation are therefore vulnerable to criticism.

Such a conceptual evaluation has been performed for the present system in that they have been explicitly designed to meet certain needs found in the analysis of emergency management problem. Thus, the Studsvik group's analysis (Johansson, et al., 1986) of emergency organisation drills resulted in the specifications for the message handling system. Specifically, the Studsvik group concluded that decision makers in the emergency organisation may not always have a clear picture of the situation, and that this could be understood in terms of deficiencies in the information flow.

The reminder functions were designed on the basis of experimental results by Belardo, Karwan and Wallace (1984), which strongly indicated the need for a reminding function in that they found, (1) that many tasks were forgotten in emergency management, and (2) that introduction of memory aids improved performance.

A second form of a more limited evaluation is a function evaluation. Such an evaluation involves an attempt to ascertain whether the functions built into the system actually have the effects that have been assumed by the designers of the system. This involves testing the system under conditions where the functions built into the system could be used to advantage, and assessing (1) whether they are in fact used, and (2) whether they lead to better performance.

The method chosen for the empirical evaluation of the present system was that of a function evaluation. Specifically, the empirical evaluation was an attempt to assess the extent to which the message handling function and the reminder function had the effects assumed in the specification, i.e., whether the message handling function would lead to a better understanding of the situation and whether the reminding function led to more of the necessary tasks in the emergency plan being performed.

7.2 General characteristics of the evaluation.

The general plan for the evaluation was to have persons who have experience in emergency management perform in scenarios which required them to actually carry out all the tasks required by the emergency plan. Care was taken to construct scenarios that would be realistic with respect to the number of tasks that would have to be performed and with respect to their real time characteristics. Thus, these scenarios would require the subjects to have a good understanding of the situation and to remember their tasks.

Two experiments were carried out, one involving the on-site system and one involving the off-site system. Two scenarios were constructed for each evaluation.

The on-site scenarios required the subjects to take the role of plant emergency managers. The off-site scenarios required them to take the role of acting head of the organisation, i.e., the position taken by the first senior decision maker reaching the CEOC. Under normal conditions, this person holds this position until the county governor and chief of staff arrive, who then take over. However, in the present scenarios, these persons did not arrive during the scenarios, so the subject had to continue in the role of acting head throughout the scenario and thus for a longer time than would normally be the case.

The scenarios for the on-site evaluation involved emergencies at the Loviisa nuclear power plant in Finland. The off-site scenarios involved emergencies at the Forsmark nuclear power plant outside of Uppsala.

7.3 Design

The design of both the on-site and off-site evaluation experiment followed a within-subjects design, so that each subject performed in two scenarios, one with the system (the experimental condition) and one without the system (the control condition). This was necessary because there are very few qualified subjects for experiments of this kind to design experiments with different subjects in each condition.

7.4 Subjects

In the on-site evaluation, the subjects were four members of the staff of the Loviisa nuclear power plant who all had experience as plant emergency manager from drills at the plant.

In the off-site evaluation, the subjects were five senior civil servants from county government (länsstyrelsen) in Uppsala county. All of them had regular assignments in the county emergency management organisation and considerable experience in various positions in that organisation.

7.5 Scenarios

The scenarios were constructed as real time scenarios of nuclear emergencies. Each scenario lasted for about 2 1/2 hr.

The scenarios were designed as a series of messages which were sent to the subjects and required some kind of response or decision, including actions to carry out the emergency plan as the scenario developed. To carry out their tasks, the subjects had to send messages, either via the computer system or via telephone or telefax.

Care was taken in the development of the scenarios to have the sequence of events unfold in real time. When subjects asked for additional information, or for tasks to be carried out that had not been foreseen in the scenario, an attempt was made to have these tasks take the time they should reasonably take, and if the subjects asked for information about how the tasks were carried out before they could reasonably have been completed, he or she was told that the task had not yet been completed, or that no information was available.

7.5.1 On-site evaluation.

The scenarios used in the on-site evaluation were based on earlier drills at the Loviisa plant.

Both scenarios on-site are mainly LOCAs (loss of coolant accidents). They differ in consequences for people and environment, but also in technical detail.

Scenario 1 starts with a very small leakage in an emergency cooling system. The leakage grows to a big pipe break when the repair team is working on it. The repair team is injured and the situation turns into a site and general emergency. The releases to the environment are relatively small.

The initiating event of scenario 2 is a large leakage in the primary circuit. This causes reactor and turbine trips which in turn leads to a loss of electricity supply from the national grid. This together with some malfunctions in the process leads to radiation releases to the environment. Some of the communication links to the outside world are not operating properly.

7.5.2 Off-site evaluation.

The scenarios used in the off-site evaluation were based on plant specific conditions, features and accident analyses pertaining to the Forsmark power plant, and on specific organisational and geographic conditions related to the County of Uppsala and its County Board. Consequently, the scenarios could not be used for other sites without modification.

As for the on-site evaluation, two scenarios were developed with two different types of accidents. The technical background as well as the time scale and the sequence of events differ for the two scenarios. The two accidents make different demands upon the CEOC.

Swedish nuclear power plants are equipped with filtered containment venting systems. When pressure in the containment is relieved through the filter system, the release will be at most 0-1% of the core inventory, excluding noble gases. The containment spray accomplishes the containment flooding, but the atmosphere has to be relieved through the filter to meet the requirements with respect to ambient containment pressure. This becomes necessary in one of the scenarios. In the other scenario, the filtered containment venting system is by-passed as a consequence of an isolation valve failure. Two scenarios will be described shortly in the following.

Scenario 1: Steam line break - LOCA accident with unfiltered release of activity. The scenario starts with a main steamline break outside the containment. The reactor shut down succeeds, but the reactor cooling systems fail for various reasons. The core is partly uncovered for 20-30 minutes until re-flooding is successful. When the core is uncovered, several fuel pins burst, and cause a radioactive release. Furthermore, the isolation valves in the broken steamline fail. As a consequence of the isolation valve failure, a pathway release of radio-activity to the environment is established.

Isolation of the steam line succeeds 1.5 hr after the break. At that time the release to the environment stops.

An emergency alarm is given to the CEOC and the Alarm station in

Uppsala. The subject then has to decide about what actions in the emergency plan that are called for. He/she has to be in contact with SSI and SKI. Other authorities also contact the CEOC asking for information and instructions. In addition, some interaction within the emergency organisation and with the public is required.

Measurement values are provided by the Forsmark plant and by the head of the indication group, which is part of the emergency organisation.

Scenario 2: Reactor core melt down with subsequent release of radioactivity from the containment building. Scenario 2 started with a loss of off-site power with subsequent diesel generator failure at F3 until all DC power is lost. This means that core cooling becomes impossible. The core therefore becomes uncovered and superheated. Subsequently, the core starts to melt, and approximately 1.5 hr after the power failure, the core melts through the reactor pressure vessel. After the core melt, the crew manages to fill the containment with water using external mobile pumps. The pressure in the containment due to the increasing amount of water has to be relieved through the filter within 24 hr to meet the requirements with respect to ambient containment pressure. The CEOC can determine the time of the release, within certain limits, to minimise the consequences for the public.

The scenario starts with a telephone call from a journalist who asks for details about the awkward situation in Forsmark. Shortly after that, the information about a non-normal event reaches the CEOC. After only 20 more minutes, there is a general emergency alarm. The CEOC must now take action according to the emergency plan. Information from SKI and SSI is available about 1 hr after the initial event. As in the first scenario, various internal and external agencies present problems and requests for information.

The subject faces two problems: to decide about appropriate protective actions motivated by the unstable situation before the release, and to decide about the appropriate time for the planned depressurisation, and the appropriate protective actions to be taken in connection with this release.

7.6 General experimental set-up

In both the on-site and off-site evaluations, the experiment was carried out using two rooms, as illustrated in Figure 7.1. One room represented the plant emergency manager's office and the CEOC, respectively, while the other represented the rest of the world, so to speak. The subject was in the former room, together with the experimenter, who observed his or her behaviour, and carried the telefax messages when required. In the experimental condition, the subjects were also provided with an intelligent interface in the form of an operator to help the subject use the information system. This was necessary because there was very little time for special training with the information system.

In the experimental conditions, the subjects had three means of communication: the computer system, telephone and telefax. They were allowed to use whatever system they wanted. In the control condition, the subjects could only communicate via telephone and telefax.

In both conditions, the subjects had access to their ordinary handbook for emergency management. In the case of off-site emergency management, this handbook contains all procedures and tasks to be performed, lists of personnel, and maps and information about radiation measurement sites and about the population of the area. In the on-site case, the handbook has the corresponding information relevant for the on-site emergency management and organisation. Thus, this handbook contained all the information available in the computer about the emergency preparedness guide, as well as information not available in the computer system.

In the off-site case, the subjects also had a map of the relevant area around the Forsmark plant as they would have in the real CEOC.

In the other room there was one or two persons, whose task it was to send the messages in the scenario via the computer (in the experimental condition) or via telephone (in the control condition). These persons also answered all questions that the subjects might have, and generally responded to the subjects' decisions in the way required by the scenario. This required

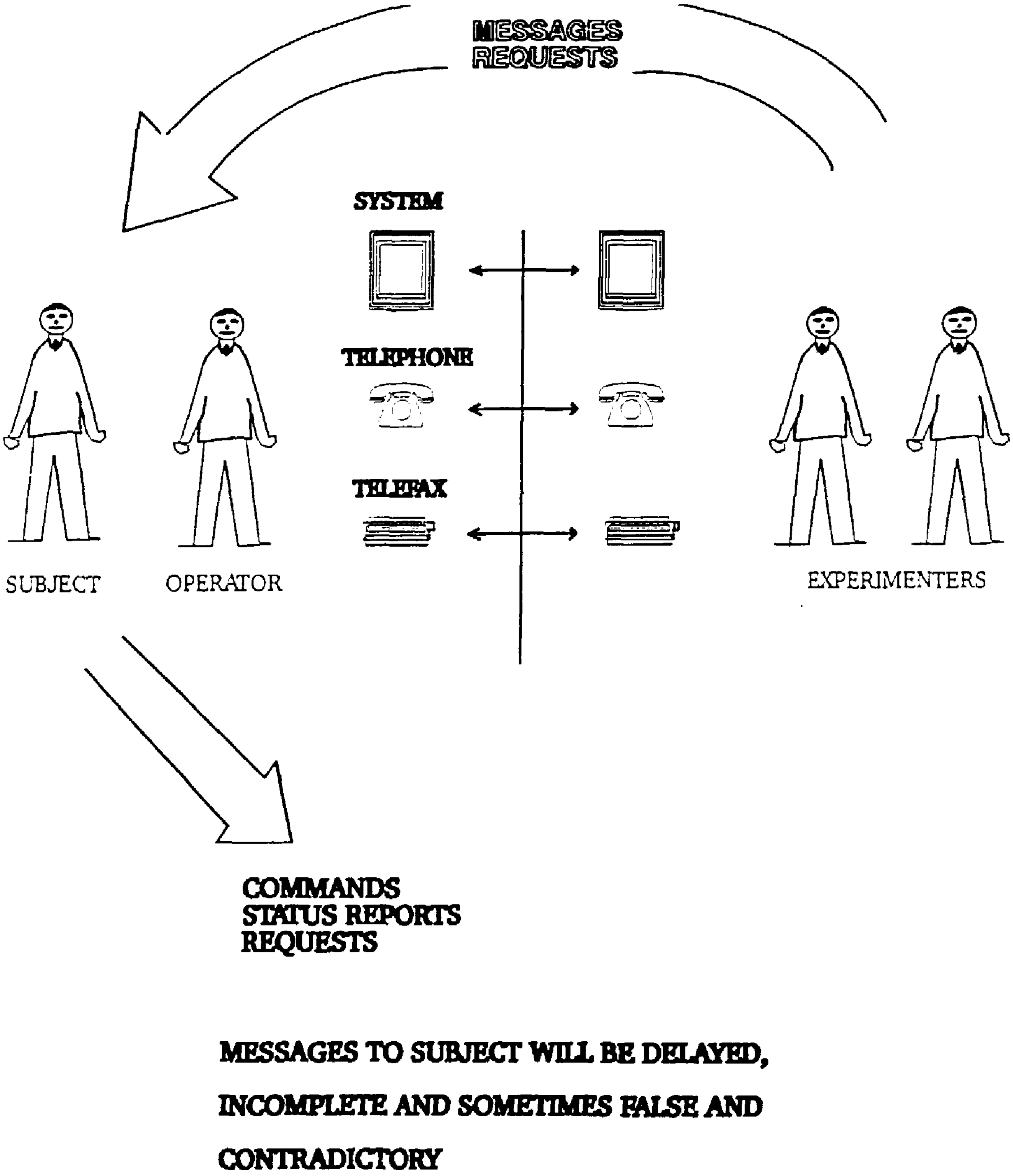


Figure 7.1 Schematic set-up of experiment.

considerable powers of improvisation, and thus extensive knowledge of the nature of nuclear emergency management in general and the scenarios used in the experiment in particular, for not all questions and actions by the subjects had been foreseen in the design of the scenarios. Thus, these persons truly played "the rest of the world".

7.7 Dependent variables

All messages sent via the computer system were recorded and a hard copy taken. All telephone conversations were recorded and transcribed. As no decisions can be taken without communication, these records provide a complete account of the decisions actually made in the scenario, and it is possible to ascertain the extent to which the subjects actually carried out their tasks by examining these records. These records provide a rich source for the analysis of decision making during emergency management. However, in the present context the analysis has been limited to those aspects that are relevant to the evaluation of the information system, i.e., the extent to which the subjects carried out the tasks in the emergency preparedness guide.

To measure the extent to which the subjects achieved a good understanding of the situation, they were given a press release to edit every hour. These releases contained errors, and the extent to which these errors were detected provides an additional measure of the extent of which the subjects have a good understanding of the situation. However, the best assessment of that is, of course, whether they performed the tasks in the emergency preparedness guide in an appropriate way.

In addition, the subjects were interviewed after they had completed the second scenario. The interview was performed to obtain measures of user satisfaction and suggestions concerning how the system could be improved. Thus, the interview covered three areas: the extent to which the subjects found the system useful in the experiment, the extent to which the system would be useful in a real emergency management situation, and how the system could be improved.

8. RESULTS AND EVALUATION

8.1 Performance of the tasks

Considering the few subjects involved in the experiments, it was not possible to detect any statistically significant differences in how the tasks were carried out in the experimental and control conditions. The end situation was similar. and in both conditions the subjects brought the emergency under control.

The emergency preparedness guide - which served as a major memory aid - was used in both conditions, either in the form of the handbook or in the form of the guide in the computer system. Thus, subjects had the same memory aids in both conditions, and used them in the same way.

The special reminding function was generally not used. In the few cases when it was used, this seemed to be more out of curiosity in seeing how it would function than out of real need for being reminded.

Analysis of the press releases revealed no differences in understanding of the situation in the two conditions.

User satisfaction was generally high in the off-site evaluation. All subjects found the system useful in the experiment, and thought that it would be useful also in a real emergency. One subject said that he preferred working with the system compared to working with the real organisation, but the other subjects thought that it would only be a complement. Specifically these subjects found the communication via the system cold and impersonal and thought that it led to loss of important information that would be available in face-to-face communication. With the system, there was no immediate feedback from the other people, and no way of assessing the morale and state of mind. The automatic documentation provided by the system was considered useful in that it relieved the subjects of a task that they would otherwise have to perform manually.

In this context, it is interesting to note that the subjects, both in the on-site and off-site evaluations often had a number of unread messages in the system, turning to these when they had completed whatever task they were performing. This suggests that the subjects had a greater control over their own working situation with the system than they had in the control condition where they were often interrupted by telephone calls. However, this did not adversely affect their performance in the control conditions. In a real emergency, much of the communication would presumably be in written form just as in the experimental condition here, e.g., in the form of telefaxes, and may end up in a pile of unread messages, just as was the case when the subjects worked with the system. However, it seems reasonable to assume that it would be harder to find the unread messages from such a pile of telefaxes and other pieces of paper than with the system.

The off-site evaluation subjects pointed to the automatic logging of messages as an important advantage of the system. Compared to traditional forms of logging, the system could provide one important advantage: the information might be made available to all members of the emergency organisation in a simple way.

The subjects in the off-site evaluation thought that they had learned about emergency management from taking part in the experiment, especially when working with the system. This gave a better overview of what went on than one would usually get from taking part in a drill. They therefore thought that the system could fill an important function in training people in the emergency organisation.

The subjects in the on-site evaluation were less enthusiastic. One of the four subjects in this condition refused to use the system, finding it too cumbersome, and used the telephone instead. The other subjects remarked on the lack of face-to-face communication, which led to considerable uncertainty about what was going on. At least one of the subjects was certain that he would not use the system in a real emergency. This difference between the on- and off-site evaluations is easy to understand in view of the actual communication patterns. A large part of the communication of the Plant Emergency Manager is with persons who are in the same room (the Emergency Operations Facility). In the off-site evaluation, on the other hand, more of the communication is with various agencies at some considerable distance from the CEOC, e.g., the plant, the police, SKI and SSI, so here the communication via the system did not disturb the usual patterns of face-to-face contact.

The subjects in both evaluations agreed that the system in its present form was too difficult to use without the aid on a trained operator. If such a system were to be installed in the emergency operations centres, even in a simplified and more user friendly form, it would require an operator. This should, perhaps, not only be taken as a criticism of the interface of the present system, but also as an expression of kinds of functions the subjects would be willing to actually perform in an emergency.

8.2 Suggestions

The subjects offered a number of suggestions concerning how the system could be improved.

- It should be possible, not only to see which messages had been sent and received, but also which of the messages they had sent that had not been answered,

- Maps with radiation measurement would be useful,

- There should be a hard copy of all messages,

- The windows containing messages received and sent should be larger so that there would be less need for scrolling,

- The system should be operated by someone at a master terminal who read all messages and routed them to those who needed them, either for taking action or for their information.

8.3 Discussion

It was impressive how well the subjects did in both the experimental and the control condition. As a consequence of the high level of performance in the control condition, when the subjects worked without the information system, there was not much chance of detecting any effects of the system. There are at least four possible explanations for this.

The first possibility is that the scenarios were too simple, and that they did not make the kinds of demands that a real emergency does. This is true to some extent, for in these experiments, the subjects worked alone, and they were freed from their ordinary organisational tasks that would have been necessary to make the CEOC function smoothly in a real emergency. But even if these organisational tasks are demanding and require much time, they are nevertheless routine tasks and they are not central to the decision making tasks evaluated here. In this latter respect, the emergency scenarios were designed to incorporate all those events that would be part of a real emergency, and for considerable periods of time in these scenarios, the subjects were quite busy carrying out their tasks.

Another factor here is that the "rest of the world" was played by one person. Thus, regardless of whether he answered questions in his role as SSI, SKI or Plant emergency manager, he did so with a complete picture of the total situation. As a consequence, the answers the subjects got may well have been better than those they would have received in a real emergency. This may be part of the explanation why the subjects performed so well in both scenarios.

The third possibility is that the scenarios did not adequately test the functions of the information systems. Even though there were quite a number of messages, they were all rather accurate, there was no false information or misunderstandings in the messages, and they arrived in an appropriate order. It should be noted that, in view of the origins of these messages and the progress of the accident, there seemed to be no possibilities of designing the messages in any other way.

A fourth possibility is that Johansson, et al (1986) in their analyses of results from drills overestimated the general work load on the decision makers in the organisation. There are two arguments for this. First, these analyses were made at a stage when the research group had not yet learned so much about the emergency management task, and this may have made this seem more complex than it is to experienced decision makers in the emergency management organisation. Second, these analyses were based on drills during 1985. Since then, the off-site organisation has been revised and the members of the organisation have accumulated considerable additional experience. This is especially true of the organisation in Uppsala from which the subjects in this evaluation came. This organisation was heavily involved in the Chernobyl disaster: Uppsala county was subject to radioactive fall out from Chernobyl and it was first thought that this fall-out came from the Forsmark plant close to Uppsala, therefore the emergency organisation was activated and had to operate for a number of days. This gave the organisation valuable experience, and may well have led to a better organisation and better procedures. It may well be, therefore, that an analysis of a drill of the kind undertaken by Johansson et al in 1985 would have revealed fewer problems in the current Uppsala organisation than was found in the original analyses.

Observations of the subjects showed that they were able to use their experience from earlier drills in ways that simplified the task. Once the subjects had identified the kind of problem they were working with, they seemed to have standard scripts for handling it. Consequently, new information could be fitted into a well formed scenario, and the problems of keeping a good understanding of the situation seemed not to be overwhelming. This is not to say that the subjects' understanding of the situation always was the same, but due to the limited action possibilities, this did not lead to any great differences in actual decisions. Once the level of emergency has been determined, the decisions are structured by the emergency preparedness guide, leaving little room for individual differences in decisions.

There is some support for this third alternative following the discussions with representatives from the CEOC in Uppsala who claimed that, even though an information system might be needed, it was not needed to support the decision making of the head of the CEOC. Instead, such a system would be more useful to support the work of the information department, which receives a great number of messages from the public, or the situation department in its handling of radiation information.

The subjects found the electronic form of communication cold and impersonal. They felt that it led to a loss of information, especially about the morale and state of mind of the sender or of a message, information that could be critical in a real emergency. Hence, they did not think that electronic mail should replace other forms of communication in emergency management.

The subjects missed the status reports that they would ordinarily have from the other staff members, and thus felt a lack of feedback concerning whether their decisions had been implemented. One subject in the off-site evaluation decided to do something about this, and called the experimenters to regular staff conferences every hour, where they had to play the role of the ordinary staff members and report on the extent to which various decisions had been implemented. This could have been included in the scenarios. However, all interaction among different parts of the organisation was deliberately excluded. The scenarios focused upon the decision making function, not the management of the organisation. This, of course, led to less realism, but then the purpose of the evaluation was not full scale realism, but evaluation of selected functions, with scenarios that made these functions important.

The subjects from the county emergency organisation expressed a wish to have available some form of the system in their organisation. Moreover, subjects in both evaluations thought that the system would be very useful for training decision makers in the emergency organisation, something that is now only possible in expensive full scale drills. The prospects for a training system are now being evaluated by the Swedish Rescue Services Board.

The fact that no positive effects of the information system could be detected in the present evaluation does, of course, not mean that such system would not prove effective under different conditions, especially in the off-site organisation. It may be true that under most (but perhaps not all) kinds of emergencies, the head of the CEOC does not have to handle enough detailed information with respect to the emergency situation to warrant a system of the kind developed here. There are, however, parts of the emergency organisation that experience considerable information loads, notably the status department and the information department. Specialised systems for these parts of the organisation may well prove to have positive effects on organisational performance. Moreover, there are situations when systems of the present kind may well prove beneficial, e.g., when there is a change of personnel, and when the new head of some department of the organisation needs to assess the situation. Another situation when the systems may prove useful is when the emergency goes on for a very long time, and when there may be need to go back to old messages to assess the situation. Thus, there are a number of additional scenarios that should be tried before we draw any more definite conclusions about the usefulness of information systems for emergency management. However, time constraints made it impossible to test the system also under these conditions. The positive reactions from the personnel from the Uppsala county emergency organisation suggest that further tests may well be worthwhile.

9 CONCLUSIONS

The project started out to find ways of using modern information technology to support emergency management in general. Based on the Chernobyl accident in 1986 the scope was restricted towards the nuclear industry. However, lessons could be learned for emergency systems in other industries as well, especially in emergency management related to the environments of process industries.

In the project it was demonstrated that information systems - especially developed for emergency management - can be computerised with the following advantages:

- simplified access to the procedures in the preparedness plan,
- automatic logging and time tagging of actions thereby relieving the production of status reports,
- standardised procedures in message handling to ensure that nothing is forgotten,
- categorisation, automatic time tagging, and filing of messages to facilitate later access to and use of these messages.

The conceptual work was directed at analysing the general problems of emergency management for the unfamiliar forms of accidents that may be caused by modern technology, emergencies for which there is no relevant prior experience.

Concerning emergency management in general in process industry the best choice for a decision support system will depend on the requirements of the expected situation. Elements from distributed decision making will be useful from the point of view of fast performance, whereas hierarchical systems will be useful if handling of different time scales or spatial scales is important. However, distributed decision making as well as hierarchical systems suffer from limitations as a general organisation for management of unknown emergencies.

The analysis of nuclear accidents shows that we may not know all the ways in which they may arise, but we know much about how they will develop and what needs to be done, especially by the off-site organisation. Therefore, in situations where precursors may be defined, it seems from the present analysis as if the most effective way of coping with nuclear emergency situations is to consider emergency management as a control system using feed-forward control.

The information system developed in this project has been evaluation by running live experiments using the prototype systems and comparing with control experiments. Since only part of a decision support system was implemented, it is very difficult to draw general conclusions, even if only functional evaluation is considered.

To demonstrate the improved performance of the system, we ought to test emergency management using the implemented functions on emergency situations being so challenging that the normal procedures would show decreased performance. The scenarios designed in the project were not sufficiently challenging. In all the control experiments the end result was complete control of the emergency situation leaving only limited space for showing improved performance by use of the new system. Though, the excellent performance by the test subjects in the control experiments is not surprising since they were professional persons, equipped with the tools they normally use when handling similar situations.

It is remarkable that after only half an hour of introduction, performance with the new system is as efficient as the familiar way of coping with such problems. This indicates that with the subjects being somewhat more familiar with the computerised system, the system will contain a potential for increased performance.

Additionally, even though the advantage of storing and being reminded of unread messages was not mentioned directly by the subjects, it seems from the experiments as if this function improved the control of the working conditions.

Furthermore, user satisfaction and the request to have a form of the system for training are other indications of the value of the system.

An important lesson to be learned from the project is that extreme care is needed in the analysing phase when test set-ups are selected. As the system has been developed to support ighly loaded and stressing communication, it would have been more worthwhile to support the information department of the County Emergency Centre with the new system instead of trying it out on the head of such organisation. This has also been pointed out by some of the subjects.

Likewise, the system ought to be tested on a person normally working alone - as it has been developed for that kind of situation - rather than trying it out on a person normally working in a team of persons as is the case for the Plant Emergency Manager.

Besides, it could have been interesting to run experiments using test subjects less familiar with specific emergency situations to try out if the system could support that category of operators to obtain an improved performance instead of using experts as we did.

Unfortunately, new tests concerning the modifications mentioned above were not performed due to the limited time available for the project.

However, the results indicate that modern information technology may improve the survey of an emergency situation, which again may improve performance, especially in the extremely rare situations, which we know by experience will show up in the nuclear as well as in the process industry.

Based on the results of this project it has been decided to continue along the same lines, and the work is now carried on in an ESPRIT project, where a complete demonstration will be possible.

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